

for exposure to radiation. Such characteristics are: Individuals must be doing the same kind of work, referred to as activity, and all members of the group must have a common relationship to the radiological environment in terms of time, location or other factors. Identification of these groups is based upon research of historical records, technical reports or correspondence. A military unit may consist of several groups or several units may comprise a single group. Using proven statistical methods, the badge data for each group is examined to determine if it adequately reflects the entire group, is valid for use in statistical calculations, or if the badge data indicate the group should be sub-divided into smaller groups. For a group that meets the tests described above, the mean dose, variance and confidence limits are determined. An estimated dose equal to 95% probability that the actual exposure did not exceed the estimate is assigned to unbadged personnel. This procedure is statistically sound and will insure that unbadged personnel are assigned doses much higher than the average/mean for the group.

(3) Dose reconstruction is performed if film badge data are unavailable for all or part of the period or radiation exposure, if film badge data are partially available but cannot be used statistically for calculations, special activities are indicated for specific individuals, or if other types of radiation exposures are indicated. In dose reconstruction, the conditions of exposure are reconstructed analytically to arrive at a radiation dose. Such reconstruction is not a new concept; it is standard scientific practice used by health physicists when the circumstances of a radiation exposure require investigation. The underlying method is in each case the same. The radiation environment is characterized in time and space, as are the activities and geometrical position of the individual. Thus, the rate at which radiation is accrued is determined throughout the time of exposure, from which the total dose is integrated. An uncertainty analysis of the reconstruction provides a calculated mean dose with confidence limits. The specific method used in a dose reconstruction depends

on what type of data are available to provide the required characterizations as well as the nature of the radiation environment. The radiation environment is not limited to the gamma radiation that would have been measured by a film badge, but also includes neutron radiation for personnel sufficiently close to a nuclear detonation, as well as beta and alpha radiation (internally) for personnel whose activities indicate the possibility of inhalation or ingestion of radioactive particles.

§218.2 General procedures.

The following procedures govern the approach taken in dose determination:

(a) Use individual film badge data where available and complete, for determining the external gamma dose.

(b) Identify group activities and locations for period(s) of possible exposure.

(c) Qualitatively assess the radiation environment in order to delineate contaminated areas. If no activities occurred in these areas, and if no other potential for exposure exists, a no dose received estimate is made.

(d) If partial film badge data are available, define group(s) of personnel with common activities and relationships to radiation environment.

(e) Using standard statistical methods, verify from the distribution of film badge readings whether the badged sample adequately represents the intended group.

(f) Calculate the mean external gamma dose, with variance and confidence limits, for each unbadged population. Assign a dose equal to 95% probability that actual exposure did not exceed the assigned dose.

(g) If badge data is not available for a statistical calculation, conduct a dose reconstruction.

(h) For dose reconstruction, define radiation environment through use of all available scientific data, e.g., measurements of radiation intensity, decay, radioisotopic composition.

(i) Quantitatively relate activities shielding, position, and other factors to radiation environment as a function of time. Integrate dose throughout period of exposure.

(j) Where possible, calculate mean dose with confidence limits; otherwise

calculate best estimate dose or, if data are too sparse, upper limit dose.

(k) Compare calculations with available film badge records to verify the calculated doses. Whether or not film badge data is available, calculate initial and internal doses where identified as a meaningful contribution to the total dose.

§218.3 Dose reconstruction methodology.

(a) *Concept.* The specific methodology consists of the characterization of the radiation environments to which participants through all relevant activities, were exposed. The environments, both initial and residual radiation are corrected with the activities of participants to determine accrued doses due to initial radiation, residual radiation and/or inhaled/ingested radioactive material, as warranted by the radiation environment and the specific personnel activities. Due to the range of activities, times, geometries, shielding, and weapon characteristics, as well as the normal spread in the available data pertaining to the radiation environment, an uncertainty analysis is performed. This analysis quantifies the uncertainties due to time/space variations, group size, and available data. Due to the large amounts of data, an automated (computer-assisted) procedure is often used to facilitate the data-handling and the dose integration, and to investigate the sensitivity to variations in the parameters used. The results of the gamma data calculations are then compared with film badge data as they apply to the specific period of the film badges and to the comparable activities of the exposed personnel, in order to validate the procedure and to identify personnel activities that could have led to atypical doses. Radiation dose from neutrons and dose commitments due to inhaled or ingested radioactive material are not detected by film badges. Where required, these values are calculated and recorded separately.

(b) *Characterization of the radiological environment.* (1) This step describes and defines the radiological conditions as a function of time for all locations of concern, that is, where personnel were positioned or where personnel activi-

ties took place. The radiation environment is divided into two standard categories—initial radiation and residual radiation.

(2) The initial radiation environment results from several types of gamma and neutron emissions. Prompt neutron and gamma radiation are emitted at the time of detonation, while delayed neutrons and fission-product gamma, from the decay of radioactive products in the fireball, continue to be emitted as the fireball rises. In contrast to these essentially point sources of radiation, there is gamma radiation from neutron interactions with air and soil, generated within a fraction of a second. Because of the complexity of these radiation sources and their varied interaction properties with air and soil, it is necessary to obtain solutions of the Boltzmann radiation transport equation. The radiation environment thus derived includes the effects of shot-specific parameters such as weapon type and yield, neutron and gamma output, source and target geometry, and atmospheric conditions. The calculated neutron and gamma radiation environments are checked for consistency with existing measured data as available. In those few cases displaying significant discrepancies that cannot be resolved, an environment based on extrapolation of the data is used if it leads to a larger calculated dose.

(3) In determining the residual radiation environment, all possible sources are considered including radioactive clouds, radiation that may have been encountered from other tests, and radioactive debris that may have been deposited in water during oceanic tests. The residual radiation environment is divided into two general components—neutron-activated material that subsequently emits, over a period of time, beta and gamma radiation; and radioactive debris from the fission reaction or from unfissioned materials that emit alpha, beta, and gamma radiation. Because residual radiation decays, the characterization of the residual environment is defined by the radiation intensity as a function of type and time. Radiological survey data are used to determine specific intensities at times of personnel exposure. Interpolation and extrapolation are based